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CLINICAL ARTICLE

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3D printing of ultra-thin veneers made of lithium disilicate using the LCM method in a digital workflow: A feasibility study

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Abstract

Objective: This article highlights the feasibility of the additive fabrication of ultra-thin veneers made of lithium disilicate using the lithography-based ceramic manufacturing (LCM) method.

Clinical Considerations: An esthetical appealing restoration of anterior teeth with thin ceramic veneers is considered one of the ultimate challenges in restorative dental prosthetics. These sophisticated restorations can be fabricated in different ways. Both analog and digital subtractive manufacturing processes have been used to date. Either of the methods is highly demanding for the dental technician and dental engineering due to the required low ceramic layer thickness.

Conclusion: Modern additive manufacturing methods, for example LCM technology, enable the production of ultra-thin lithium disilicate veneers with layer thicknesses of down to 0.2 mm and could therefore represent a viable alternative for this indication in the future.

Clinical Significance: Digital technologies can help streamline workflows, make the outcome more predictable and reproducible, and even further optimize therapeutic restorative options such as highly esthetic veneers for anterior teeth. The reduced material thickness allows for a true non-prep solution or minimally invasive preparation.

KEYWORDS
3D printing, additive manufacturing, CAD/CAM, LCM technology, lithium disilicate ceramics, ultra-thin veneers

1 | INTRODUCTION

Minimally invasive restorative treatment concepts that preserve tooth structure are becoming increasingly popular due to reduced biological expenses.[1–6] The preferred choice of materials are ceramics,[7–9] and various manufacturing methods are applied.[10] Manual layering of veneering ceramics on refractory dies provides excellent esthetic results.[11] Moreover, manually layered veneers made of feldspathic ceramics, which are adhesively bonded to the enamel, show very good survival rates.[12]

However, the manufacturing effort is exceptionally high and the stability of these layered veneers is limited due to the low flexural strength, especially as long as they are not yet bonded to the enamel. Therefore, this restorative technique poses a considerable challenge for dental technicians and dentists during processing and placement.[13] The pressing technique, by contrast, is easier to perform and provides veneers with a higher flexural strength,[14] and the quality of fit of veneers fabricated this way can be considered excellent.[15] The high number of analog processing steps, of course, is also a significant factor in this method, and increases the overall production effort.

Digital subtractive milling based on CAD design data of the veneers represents the digital manufacturing approach at this stage. Lithium silicate and zirconia ceramics are suitable materials for computer-aided veneer fabrication. The latter can be machined dry and thus enables very thin veneer thicknesses.[16,17] Lithium silicate ceramics, on the other hand, require wet grinding with diamond burs. This leads to a high machining effort and thus to a more expensive production and, in addition, necessitates a certain minimum layer thickness to ensure that the milling results are reliable. Veneers made of zirconium oxide, on the other hand, have esthetic disadvantages due to their optical properties. The higher refractive index[18] compared to enamel and dentin causes zirconia veneers to appear unnatural. First studies on the additive fabrication of ultra-thin zirconia veneers have been published and demonstrated a marginal fit comparable to conventionally fabricated veneers.[19] Additively manufactured ultrathin occlusal veneers made of zirconia showed an adequate mechanical strength.[20]

Additive manufacturing of lithium disilicate restorations represents the latest development in the field of 3D printing of ceramics.[21–24] The application of lithium disilicate veneers additively manufactured using the LCM technology was first described by Unikovskiy et al.[25] Full veneers were fabricated for the restoration of six mandibular anterior teeth and non-prep veneers for a diastema closure in the maxilla. According to the authors, layer thicknesses of 0.1 mm were achieved in some areas.

FIGURE 1 Initial intraoral situation for the workflow simulation.

The following article describes the fabrication of ultrathin veneers made of lithium disilicate using the Lithoz LCM process (Lithoz, Vienna, Austria) with an even material thickness of about 0.2 mm over the entire veneer surface. This “proof-of-concept” intends to demonstrate the straightforwardness of the workflow, but also the quality and reliability of the outcomes that can be achieved with this new technology.

2 | PRESENTATION OF THE TECHNIQUE

The complete workflow of this innovative restorative technique is presented using a case study with veneer restorations for the maxillary anterior teeth. It is a treatment simulation based on the three-dimensional (3D) real data of the patient situation.

2.1 | Data acquisition

The TRIOS 4 3D intraoral scanner (3Shape, Copenhagen, Denmark) was used to digitally record the maxilla and mandible (Figure 1) of a 23-year-old female patient. In addition to the 3D surface data, this scanner also allows for the recording of geometry-related color information (Figure 2). The data were saved in the 3Shape-specific DCM data format.

2.2 | Virtual preparation and model fabrication

A virtual veneer preparation was performed on the maxillary anterior teeth on the labial aspect using Magics Software V14.1 (Materialise, Leuven, Belgium). The tooth structure was evenly reduced by 0.24 mm. This amount comprised the intended veneer layer thickness of 0.20 mm and a gap for the bonding resin of 0.04 mm. Modelbuilder software version 2022 (3Shape, Copenhagen, Denmark) was used for digital model preparation (Figure 3) followed by Polyjet multicolor

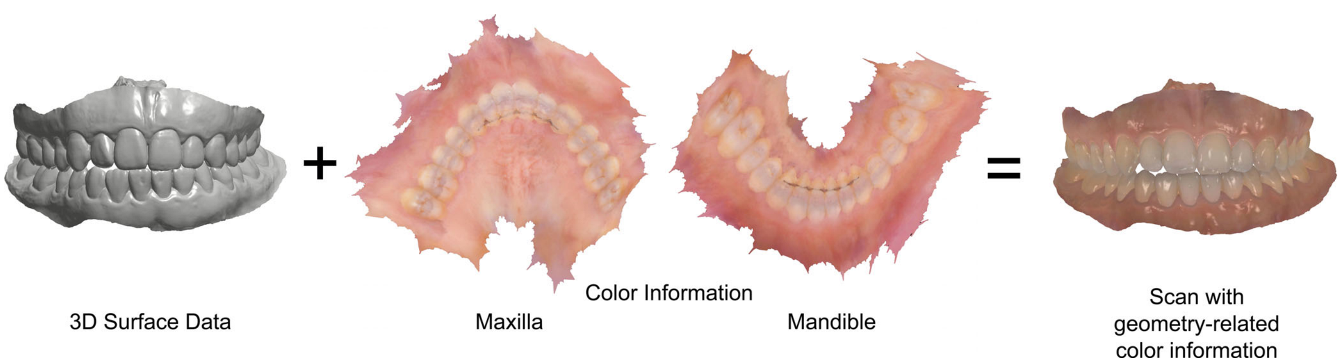

FIGURE 2 The 3D intraoral scan with the TRIOS 4 (3Shape, Copenhagen, DNK) captures the three-dimensional surface data and the geometry-related color information.

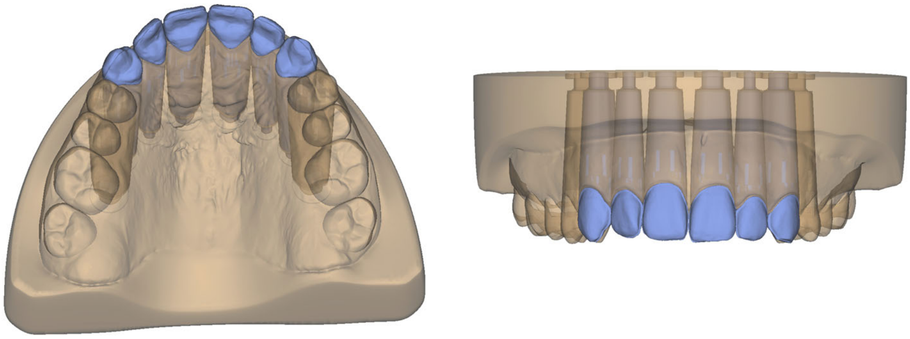

FIGURE 3 Virtual veneer preparation and digital model design.

FIGURE 4 Colored model produced using the Stratasys PolyJet method in multimaterial 3D printing.

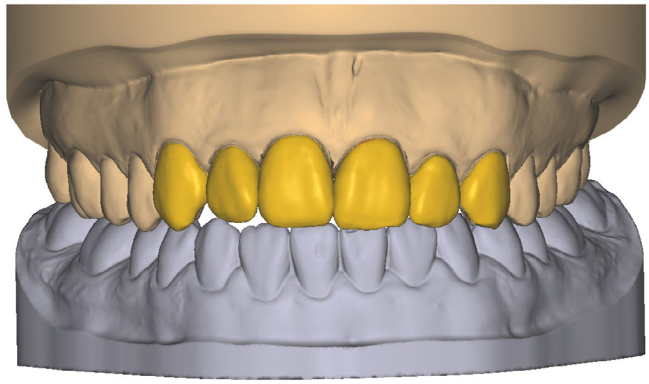

FIGURE 5 CAD design of the ultra-thin veneers.

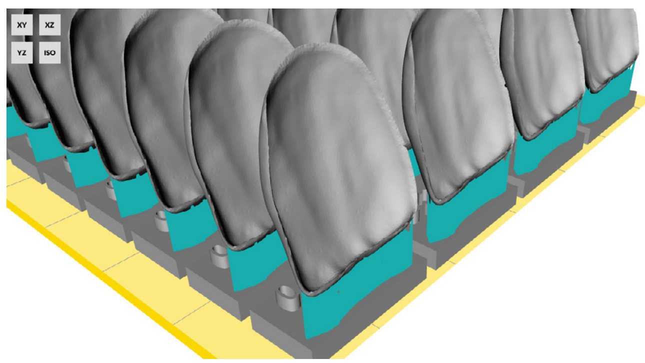

FIGURE 6 Virtual positioning of the veneers on the build platform and creation of the support structures.

printing on a Stratasys J850 Digital Anatomy 3D Printer (Stratasys, Rechovot, Israel) at 3dmedicalPrint (Attersee, Austria) (Figure 4). The six anterior tooth dies, and the distal adjacent teeth were designed to be removable abutments.

2.3 | CAD of the veneers

The veneers were created using the ExoCAD software Rijeka V3.1 (ExoCAD, Darmstadt, Germany). A gap thickness of 40 μm was chosen for the bonding resin layer. The baseline scan data of the maxilla before the virtual preparation was used as a virtual wax-up so that the design of the veneers could be fitted to it (Figure 5).

2.4 | Additive manufacturing using the LCM technology

For the 3D printing of the veneers, support structures had to be created on the CAD data to ensure a stable connection of the future restorations to the building platform of the 3D printer during the printing process (Figure 6). The data were then imported into the CeraFab S65 Medical 3D printer and the printing parameters suitable for the material were selected (Table 1). For the 3D printing, a lithium disilicate slurry in the color "Translucent" was used as a raw material for the fabrication of the veneers. The build time for each veneer shell was 6 min and 24 s. After the printing process, the parts were in the so-called "green state." These green bodies consist of a crosslinked organic binder system and lithium disilicate particles dispersed in the formulation. Excess uncured slurry was removed during the cleaning process and the parts were then subjected to thermal post-treatment (debinding, sintering, and crystallization) (Figure 7).

TABLE 1 Printing parameters for the lithography-based fabrication of ultra-thin lithium disilicate veneers with the CeraFab System S65.

Ceramic material	Lithium disilicate translucent Chemical composition based on IPS e.maxCAD lithium disilicate powder*
Layer thickness	60 [μm]
Number of layers	342
Processing time per layer	36 [s]
Total time for 3D printing of 32 veneers	3:25 [hh:mm]
Initial layer exposure intensity	50 [mW/cm^2]
Normal layer exposure intensity	50 [mW/cm^2]
Initial layer exposure energy	500 [mW/cm^2]
Normal layer exposure energy	175 [mW/cm^2]
X-Y shrinkage compensation	1.31
Z shrinkage compensation	1.35
Z exposure depth compensation	Off
Z layer exposure depth compensation	0
Contour offset	0 [px]
Support structures thickness	400 [μm]
Vat type	CeraVat UHC F (UHC = Ultra-High-Contrast)
Detergent solution	LithaSol 20

*https://lithoz.com/en/lithoz-at-ids-2023-premiere-of-3d-printed-lithium-disilicate-restorations-jointly-developed-with-ivoclar/

2.5 | Postprocessing and finalizing the veneers

To finalize the veneers, they were detached from their support structures using a water-cooled laboratory turbine and diamond red belt diamond burs. The anchor points were smoothened. After finishing the veneers and testing the static and dynamic occlusion, the crowns were finished by means of two glaze firings. These were conducted at a temperature of 710°C. In the case presented, IPS Ivocolor stains (Ivoclar) were used for this purpose (Figures 8–10).

3 | DISCUSSION

A highly translucent lithium disilicate slurry was used for the additive manufacturing of the ultra-thin maxillary anterior veneers applying the LCM technology. Postprocessing and finalizing were basically limited to the cutting and grinding of the support structures by means of water-cooled diamond burs and the glaze firing. The final thickness of the ultra-thin veneers after glaze firing was about 0.225 mm, comprising 0.2 mm veneer and 0.025 mm glaze material. The fit on the dies was accurate, and the esthetic appearance of the veneers could be considered excellent. Especially noteworthy was the excellent appearance of the sharp-edged ultra-thin margins of the veneers. Additive manufacturing proves to be beneficial in this regard, as the milling of veneers requires the restoration margin to be initially reinforced and then cut back by hand.

Standard programs were used for finalization by means of glaze firing, which meant that no rearrangements of the workflow were necessary the dental technician. The total time required for the fabrication was comparably moderate. Moreover, a key asset of the additive fabrication of ceramics is the expected low cost, which is considerably below that per unit of subtractive milling the same material.

To this date, there is only little scientific literature on the topic. Other researchers used the LCM method and ceramic materials as

FIGURE 7 Veneers after thermal treatment (debinding, sintering, and crystallization).

FIGURE 8 Finished veneers after glaze firing.

FIGURE 9 Finished veneers after glaze firing.

FIGURE 10 Veneers placed on the model.

applied in this article and addressed, for example, the topic of fabrication accuracy. The ceramic slurry comprises monomers and solvents, a photoabsorber, an initiator, and the glass ceramic filler which is Lithium oxide/Silicon dioxide with a refractive index of 1.53 and a grain size of 6 μm.[22] According to this and other previous research, dental ceramics produced using additive manufacturing technology showed high density, good translucency, advantageous mechanical properties, and high precision and reproducibility—and might therefore be a valid option for fabricating dental restorations.[21,22] The restorations with down to layer thicknesses of 0.1 mm in some areas fabricated by Unkovsky et al and published in 2022 showed acceptable esthetics and proper accuracy.[25] However, they primarily focused on restorations with a 0.5-mm chamfer preparation and non-prep veneers that substitute for a larger loss of tooth structure.

To the authors' best knowledge, this is the first time that a uniform layer thickness of only up to a maximum of 0.2 mm has been realized for dental ceramic restorations using 3D printing. The highly efficient computer-assisted fabrication of multiple ultra-thin restorations is particularly interesting when it comes to minimally invasive or non-invasive, that is, non-prep techniques in high-esthetic restorative dentistry.

An important aspect of using very thin or even “ultra-thin” restorations is how to bond these restorations safely and without fracture,

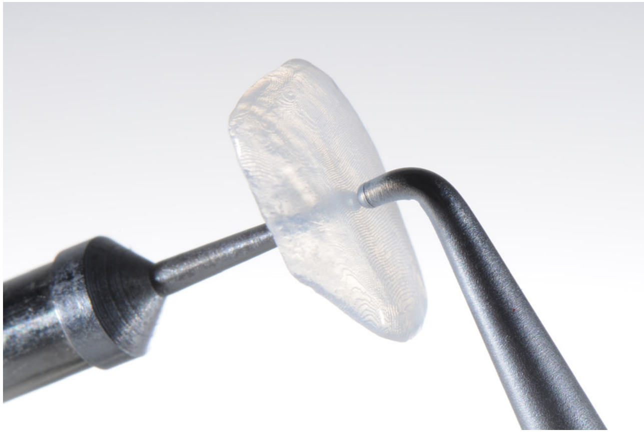

FIGURE 11 The layer thickness of the ultra-thin veneers was checked with a precision measuring instrument after glaze firing.

FIGURE 12 The total layer thickness of the veneers was 0.225 mm (0.2 mm veneer and 0.025 of glazing material).

as the thinner the restoration, the more likely a fracture will occur.[26] Recommendations for the bonding modulus can be derived from conventionally fabricated thin restorations.[26] Light-curing and very low viscosity luting composites are likely to be the most suitable, as high viscosity composites, but also for example preheated light-cured composites of higher viscosity, carry a greater risk of fractures due to their rheological properties.

3D printing of lithium disilicate ceramics has been shown to produce sufficient accuracy and excellent mechanical properties that meet the requirements for dental applications.[21] Given this, it can be assumed that veneers fabricated using this technique might be less susceptible to fracture not only during function but also during placement than those conventionally fabricated from layered feldspathic ceramics or glass-based ceramics. The degree to which this favorable aspect applies in vivo is yet to be investigated.

It can be stated that this proof-of-concept case demonstrated that it is possible to fabricate ultra-thin lithium disilicate veneers (Figures 11 and 12) in a very efficient and operator-friendly workflow using the Lithoz LCM procedure. Previous technologies (analog layering, press technology, milling) allow this only upon high effort, sophisticated operator competence, and a considerable scrap rate. Future research should emphasize improving the design software tools, investigating mechanical properties and fit parameters, and also optimizing the workflow.

4 | CONCLUSION

The additive manufacturing of veneers by means of the LCM technology shows promising economic, mechanical, and esthetic aspects compared to existing technologies. Within the scope of this proof of concept, it was shown that excellent results can be achieved with this new technology at a reasonable effort.

CONFLICT OF INTEREST STATEMENT

The authors do not have any financial interest in the companies whose materials are included in this article.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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REFERENCES

1. Loomans B, Opdam N, Attin T, et al. Severe tooth wear: European consensus statement on management guidelines. *J Adhes Dent*. 2017;19(2):111-119.
2. Edelhoff D, Liebermann A, Beuer F, Stimmelmayr M, Guth JF. Minimally invasive treatment options in fixed prosthodontics. *Quintessence Int*. 2016;47(3):207-216.
3. Guess PC, Selz CF, Steinhart YN, Stampf S, Strub JR. Prospective clinical split-mouth study of pressed and CAD/CAM all-ceramic partial-coverage restorations: 7-year results. *Int J Prosthodont*. 2013;26(1):21-25.
4. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. *Eur J Esthet Dent*. 2008;3(2):128-146.
5. Fradeani M, Barducci G, Bacherini L, Brennan M. Esthetic rehabilitation of a severely worn dentition with minimally invasive prosthetic procedures (MIPP). *Int J Periodontics Restorative Dent*. 2012;32(2):135-147.
6. Grutter L, Vailati F. Full-mouth adhesive rehabilitation in case of severe dental erosion, a minimally invasive approach following the 3-step technique. *Eur J Esthet Dent*. 2013;8(3):358-375.
7. Magne P, Magne M. Use of additive waxup and direct intraoral mock-up for enamel preservation with porcelain laminate veneers. *Eur J Esthet Dent*. 2006;1(1):10-19.

8. Cortellini D, Canale A. Bonding lithium disilicate ceramic to featheredge tooth preparations: a minimally invasive treatment concept. *J Adhes Dent*. 2012;14(1):7-10.
9. Resende TH, Reis KR, Schlichting LH, Magne P. Ultrathin CAD-CAM ceramic occlusal veneers and anterior bilaminar veneers for the treatment of moderate dental biocorrosion: a 1.5-year follow-up. *Oper Dent*. 2018;43(4):337-346.
10. Puri S. Techniques used to fabricate all-ceramic restorations in the dental practice. *Compend Contin Educ Dent*. 2005;26(7):519-525. quiz 26-7.
11. Sheets CG, Taniguchi T. Advantages and limitations in the use of porcelain veneer restorations. *J Prosthet Dent*. 1990;64(4):406-411.
12. Layton DM, Walton TR. The up to 21-year clinical outcome and survival of feldspathic porcelain veneers: accounting for clustering. *Int J Prosthodont*. 2012;25(6):604-612.
13. Sheets CG, Taniguchi T. A multidie technique for the fabrication of porcelain laminate veneers. *J Prosthet Dent*. 1993;70(4):291-295.
14. Lehner CR, Schärer P. All-ceramic crowns. *Curr Opin Dent*. 1992;2:45-52.
15. Baig MR, Qasim SSB, Baskaradoss JK. Marginal and internal fit of porcelain laminate veneers: a systematic review and meta-analysis. *J Prosthet Dent*. 2022;S0022-3913(22):00052-X.
16. Souza R, Barbosa F, Araujo G, et al. Ultrathin monolithic zirconia veneers: reality or future? Report of a clinical case and one-year follow-up. *Oper Dent*. 2018;43(1):3-11.
17. Mekled S, Elwazeer S, Jurado CA, et al. Ultra-translucent zirconia laminate veneers: the influence of restoration thickness and stump tooth-shade. *Materials (Basel)*. 2023;16(8):3030.
18. Stawarczyk B, Liebermann A, Eichberger M, Guth JF. Evaluation of mechanical and optical behavior of current esthetic dental restorative CAD/CAM composites. *J Mech Behav Biomed Mater*. 2015;55:1-11.
19. Ioannidis A, Park JM, Hüsler J, Bomze D, Mühlemann S, Özcan M. An in vitro comparison of the marginal and internal adaptation of ultrathin occlusal veneers made of 3D-printed zirconia, milled zirconia, and heat-pressed lithium disilicate. *J Prosthet Dent*. 2022;128(4):709-715.
20. Ioannidis A, Bomze D, Hammerle CHF, Husler J, Birrer O, Muhlemann S. Load-bearing capacity of CAD/CAM 3D-printed zirconia, CAD/CAM milled zirconia, and heat-pressed lithium disilicate ultrathin occlusal veneers on molars. *Dent Mater*. 2020;36(4):e109-e116.
21. Baumgartner S, Gmeiner R, Schonherr JA, Stampfl J. Stereolithography-based additive manufacturing of lithium disilicate glass ceramic for dental applications. *Mater Sci Eng C Mater Biol Appl*. 2020;116:111180.
22. Schonherr JA, Baumgartner S, Hartmann M, Stampfl J. Stereolithographic additive manufacturing of high precision glass ceramic parts. *Materials (Basel)*. 2020;13(7):1492.
23. Schweiger J. 3D lithium disilicate printing. *Med Device Develop*. 2022;1(5):56-57.
24. Schweiger J, Schubert O, Edelhoff D. 3D-Druck von Lithium-Disilikat—Zukunft oder nur Fiktion? *Quintessenz Zahntech*. 2022;48(12):1244-1250.
25. Unkovskiy A, Beuer F, Metin DS, Bomze D, Hey J, Schmidt F. Additive manufacturing of lithium disilicate with the LCM process for classic and non-prep veneers: preliminary technical and clinical case experience. *Materials (Basel)*. 2022;15(17):6034.
26. Gonzalez-Martin O, Avila-Ortiz G, Torres-Muñoz A, Del Solar D, Veltri M. Ultrathin ceramic veneers in the aesthetic zone: a 36-month retrospective case series. *Int J Prosthodont*. 2021;34(5):567-577.

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